Digital technology serves 2-way radio communications

Linear predictive vocoding digitizes voice on radio communications channels. How users migrate to digital technology has an important bearing on choosing among the three access methods.

By Tim Twohig
and Vicki Griesser

Digital voice modulation may relieve land mobile radio channel congestion, increase data transmission capacity and add advanced features.

Digital enhancements

► *Audio quality*—New linear predictive voice encoding (vocoding) techniques and forward error correction improve digital audio quality.

Semiconductor technology advances have produced digital signal processors (DSPs) that execute millions of instructions per second. Linear predictive coders use the DSPs' processing power to convert the analog voice signal to a digital signal using computational approximation. This processing type provides digital audio quality comparable to analog.

Digital systems can provide uniform audio quality throughout more of a system's coverage area. Near the transmitter, digital and analog audio quality are comparable. At the coverage area fringe, where analog audio quality suffers from noise and fading, digital audio with forward error correction can be much better. (See Figure 1 below left.)

As the radio signal weakens, noise and fading cause digital bitstream errors. The digital receiver compares inbound information with codes that correct bitstream errors to reconstruct the transmitted audio (or data message) accurately.

► *Data capability*—Digital technology can increase a radio system's data capabilities in a number of ways.

On a digital system, voice and data are transmitted in digital form, making it easier to integrate them. Data and voice transmissions can be carried on a single channel without one interfering with the other.

Digital modulation schemes support higher data transmission rates than today's two-state frequency-shift keying (FSK) modulation. Some of the next-generation digital systems will use multistate modulation techniques such as quadrature phase-shift keying (QPSK) and quadrature amplitude modulation (QAM).

These modulation techniques allow

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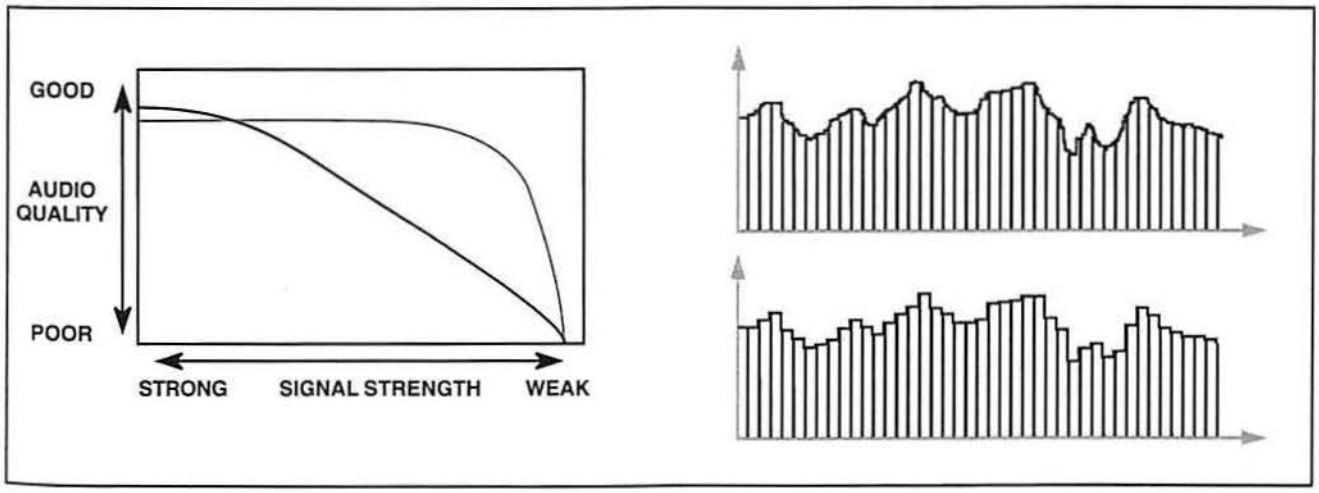

Figure 1. Digital audio quality surpasses analog quality as the radio signal weakens. At the fringe of the coverage area where analog audio quality suffers from noise and fading, digital audio with forward error correction can be much better.

Figure 2. Pulse code modulation (PCM) samples the analog voice signal many times per second. Each sample is used to reconstruct the analog signal. At a rate that maintains high voice quality, PCM sampling generates more data than can be sent over a 25kHz-wide radio communications channel.

higher data rates by representing multiple bits with each state change. Using higher data rates makes applications that are too data-intensive for two-state modulation more practical. Some applications include data transmissions to and from laptop computers, peripherals and facsimile machines.

► *Spectrum efficiency*—Digital technology can carry more communications on a given amount of radio spectrum, improving spectrum efficiency.

Voice modulation evolution

Long-distance telephone carriers were the first companies to digitize voice in the 1960s using 64kbps pulse code modulation (PCM).

PCM samples the analog voice signal level 8,000 times per second. Each sample is represented by 8 bits of digital information that are used to reconstruct the analog signal. (See Figure 2 on page 11.) This coding method provides voice transmissions over long-haul wires with minimum noise and distortion.

When digital voice is sent over radio, the amount of data that can be sent over a given bandwidth is limited to provide acceptable performance to adjacent-channel users. With two-state digital modulation, it is impossible to transmit 64kbps digital signals over a 25kHz radio channel.

In the 1970s, vocoding techniques such as continuously variable slope delta (CVSD) modulation accurately represented a human voice using only 12kbps of information. This amount of data fits on a 25kHz channel with two-state digital modulation.

Unlike PCM, which samples the analog signal's level, CVSD samples its slope. The digital signal, made of binary (ones and zeros) codes, approximates the rising slope values with ones and falling slope values with zeros. (See Figure 3 below.)

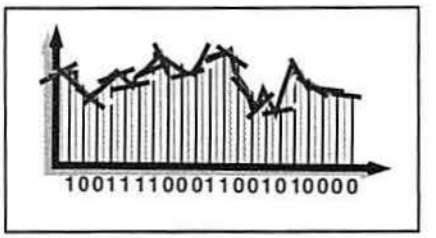

Figure 3. Continuously variable slope delta (CVSD) modulation samples the analog signal's slope. The digital signal, composed of binary (ones and zeros) codes, approximates the rising slope values with ones and falling slope values with zeros.

One bit of information represents each sample. Because CVSD vocoders degrade audio quality slightly, they are used only in encryption systems.

PCM and CVSD convert analog voice to digital voice by approximating the analog signal. Linear predictive vocoding uses the DSP's computing power to digitize voice by approximating the voice *process*.

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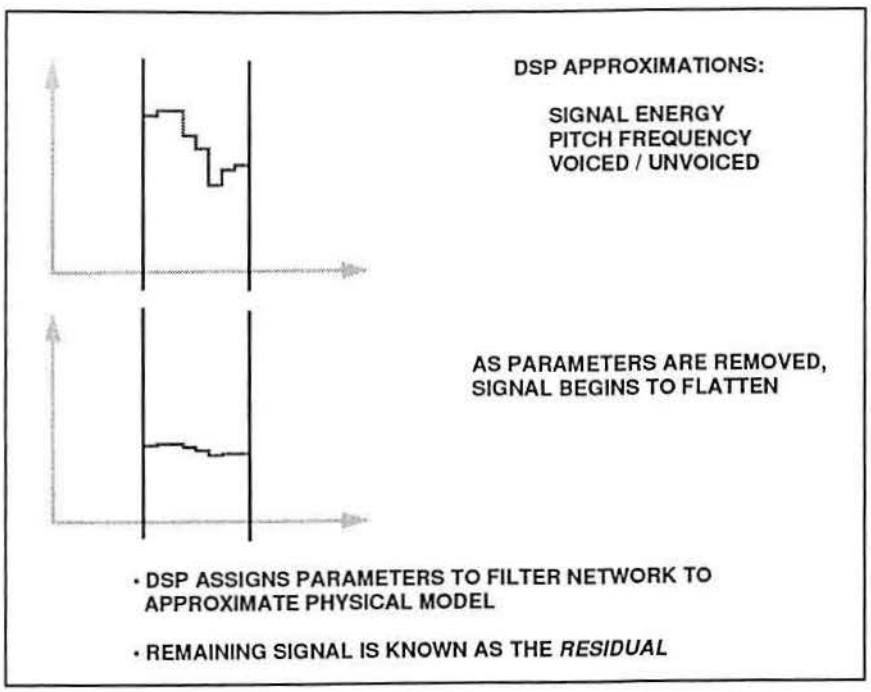
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• REMAINING SIGNAL IS KNOWN AS THE RESIDUAL

Figure 4. Linear predictive coding transmits filter coefficients that approximate speech patterns. Additional speech pattern information stored in the receiver is accessed by residual sequence address codes and combined with the filter coefficients to improve the digital audio quality.

pulses) for voiced sounds or air noise from the lungs for unvoiced sounds. Linear predictive coding derives coefficients for a filter structure that approximates this process.

The linear predictive coding process has several steps. (See Figure 4 to the left.)

First, the analog signal is digitized using 64kbps PCM. This digital stream is divided into relatively short speech segments that the DSP processes. The DSP derives the filter coefficients that approximate the speech pattern and sends them to the transmitter.

Reconstructing the signal from these coefficients alone results in understandable, yet mechanical sounding, speech.

Audio quality improvements are achieved when the *residual* sequence, which is the difference between the input signal and the approximated signal, is transmitted. But transmitting the entire residual sequence results in a higher bit rate requirement, which in turn affects this method's efficiency.

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residual sequences was derived. Instead of sending the entire residual sequence, only the residual sequence's address is transmitted. The receiving radio looks up the residual sequence in its electronic memory and adds it to the approximated signal.

Linear predictive coding requires approximately 4.8kbps of information to provide audio quality comparable to analog. This information, when combined with new modulation techniques, easily fits a 25kHz channel.

In fact, there is much more room than what is needed to send just one voice over the channel. The additional capacity makes digital radio systems more spectrally efficient than their analog counterparts.

Three digital communications technologies, FDMA, TDMA and CDMA, are suited to different radio communications applications uniquely. The technologies differ in the way they make use of the additional capacity.

► *FDMA*—Frequency division multiple access (FDMA) offers more capacity than necessary to send one 4.8kbps digital voice over a 25kHz channel, so a smaller channel or a channel with less bandwidth may be used.

One implementation of FDMA technology uses a 12.5kHz-wide channel (half the bandwidth of previous channels) and provides the capability to create twice as many channels as 25kHz-wide channels from the same amount of RF spectrum. (See Figure 5 below.)

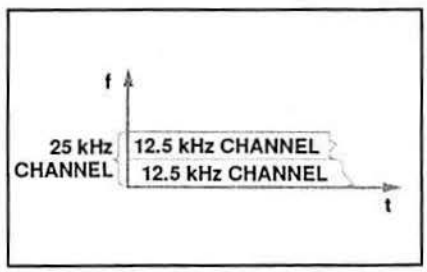

Figure 5. One implementation of FDMA technology uses a 12.5kHz-wide channel (half the bandwidth of previous channels) and provides the capability to create twice as many channels as 25kHz-wide channels from the same amount of RF spectrum.

Results of the FCC *Notice of Inquiry* concerning spectrum efficiency in land mobile frequency bands show that nearly two-thirds of respondents favor narrowband operation to reduce frequency congestion. The remaining respondents had no negative comments regarding narrowband FDMA.

There are two methods of converting existing wideband channels to digital narrowband channels. (See Figure 6 on page 18.)

The *on-channel* method places narrowband digital channels on the existing 25kHz center frequency. When adjacent 25kHz channels have been converted to narrowband channels, the 12.5kHz space between them can be occupied by a new narrowband channel.

The *offset* method places two narrowband channels in the space formerly occupied by one wideband channel. The center frequencies of the two new channels are offset 6.25kHz to either side of the wideband channel center.

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Any benefit realized through channel-splitting or converting is contingent upon local and national regulatory guidelines.

FDMA techniques have been optimized for use in the land mobile environment. A 12.5kHz digital channel using QPSK-C modulation can transmit 9.6kbps of data while maintaining the required level of adjacent channel protection.

Site issues, such as transmitter noise and receiver desensitization, still must be evaluated (as they would be with analog technology).

Because only 4.8kbps is required to represent a voice, extra capacity is available.

The extra capacity can be used to send other information such as error correction codes to ensure high audio quality; system signaling to add new features and improve existing features; and encryption information to ensure secure communication.

In today's analog systems, voice and data contend for a channel. The signaling information is sent first, and the voice message follows. This process truncates the voice.

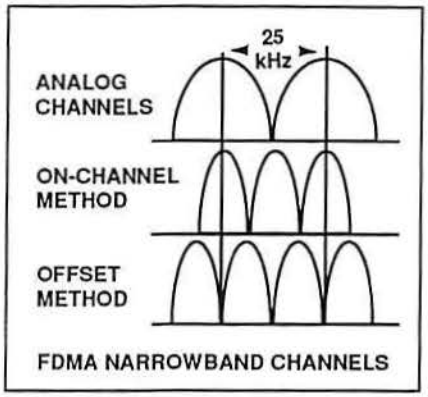

Figure 6. Converting 25kHz analog channels to 12.5kHz digital channels may be accomplished via the on-channel or offset method.

The digital system uses a process called *embedded signaling* that intermixes the extra 4.8kbps of signaling information with the digital voice.

Embedded signaling eliminates truncation and adds reliability into the system by embedding system and radio information continuously through the duration of the voice message. Features such as encryption, emergency, unit ID, automatic power control and alphanumeric messaging may be realized and made more reliable by embedding the signaling in the voice message.

Data capacity increases significantly when the communication is entirely in a data mode. Field units operating in the data mode send as much as 7.2kbps of data and 2.4kbps of error correction. Not only can digital technology provide a dramatic increase in data capacity compared to today's analog systems, but the variety of data applications can be increased as well.

Error correction codes help to ensure data integrity, adding reliability.

FDMA systems can increase spectrum efficiency by 2:1, add new features, enhance existing features and increase data capacity along with providing high audio quality in trunked and conventional radio communications systems. FDMA systems can be used in any fre-

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quency band.

► *TDMA*—Time division multiple access (TDMA) uses a 25kHz channel's additional capacity to transmit multiple voice messages simultaneously. Spectrum efficiency is accomplished by splitting the channel into repeating time slots, each of which can carry the necessary information for one voice conversation. (See Figure 7 to the right.)

One TDMA access method splits the 25kHz channel into six repeating time slots, potentially enabling as many as six users or groups of users to share the channel at any time.

TDMA technology inherently provides multiple communications paths. To use these paths effectively, some control must be placed over path access and allocation to user groups. Trunked radio technology provides the control and dynamically assigns these talk paths to users upon request.

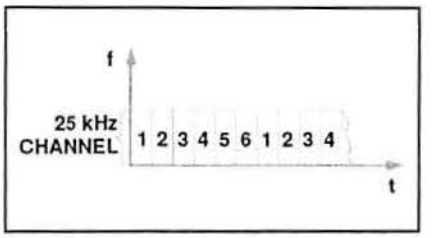

Figure 7. Time division multiple access (TDMA) uses a 25kHz channel's additional capacity to transmit multiple voice messages simultaneously. Spectrum efficiency is accomplished by splitting the channel into repeating time slots, each of which can carry the necessary information for one voice conversation.

The TDMA modulation technique has been maximized for the land mobile environment, allowing digital channels to coexist with adjacent analog channels. Nonetheless, co-channel use is a spectrum issue that must be addressed.

The mobiles and portables in this type of system must be synchronized tightly for orderly talk path assignments. Any interference that causes errors in the outbound signaling could jeopardize this synchronization. Therefore, exclusive-use channels, such as those available at 800MHz, are strongly recommended for any TDMA communications system.

Because each user only transmits and receives one-sixth of the time, the transmitter and receiver each can be assigned a different time slot, allowing full-duplex telephone interconnect calls on mobiles and portables without the use of a duplexer. With TDMA, full-duplex interconnect becomes an inherent capability, resulting in added convenience and improved economy in telephone communications.

Systems using TDMA can support data and voice transmissions on one channel using different time slots.

For example, one individual could use one time slot for a voice conversation while another individual faxes documents on another time slot.

A new linear modulation technique, M-16QAM, transmits information at 64kbps over a 25kHz channel. The higher data rates allow data-intensive applications, such as facsimile, on a TDMA system.

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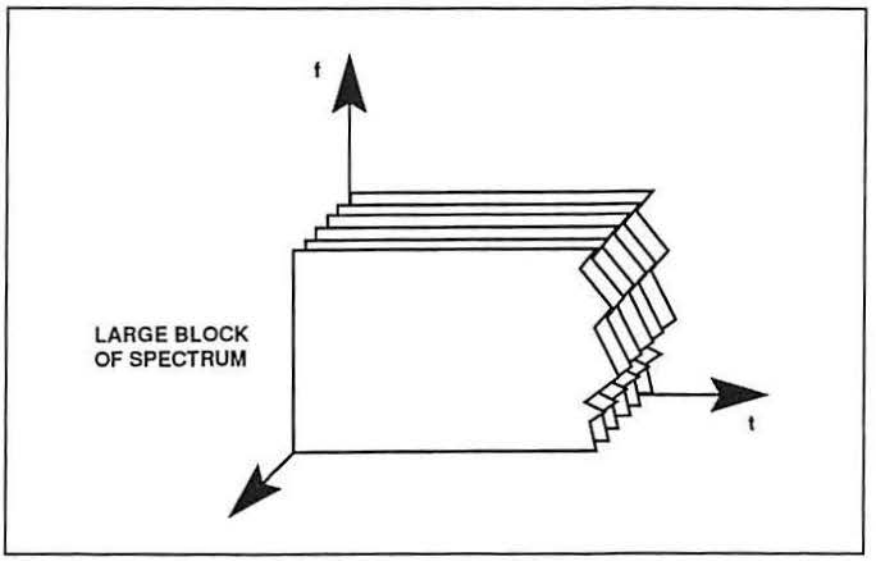

Figure 8. Code division multiple access (CDMA or digital spread spectrum) spreads the transmitted energy over a large amount of spectrum, using a low-powered signal that resists interference. Each transmission is coded so that CDMA receivers can separate the messages they are intended to receive.

Because of its dramatic increase in spectrum efficiency, TDMA technology is particularly useful in large metropolitan areas where the radio spectrum is congested. TDMA's 6:1 increase in spectrum efficiency can help to relieve overcrowding on some channels.

The technology will be useful in systems with many users sharing one RF backbone, such as specialized mobile radio (SMR) systems.

TDMA digital systems will offer full-duplex telephone interconnection, increased data capacity and high audio quality to improve trunked radio communications.

► *CDMA*—Code division multiple access (CDMA) technology uses even wider bandwidths than existing 25kHz channels to gain capacity. (See Figure 8 to the left.)

Also known as *digital spread spectrum*, CDMA spreads the transmitted energy over a large amount of spectrum, using a low-powered signal that resists interference. Each transmission is coded so that CDMA receivers can separate the messages they are intended to receive.

The combination of low-power signal and coding could allow many users to share the spectrum without interfering

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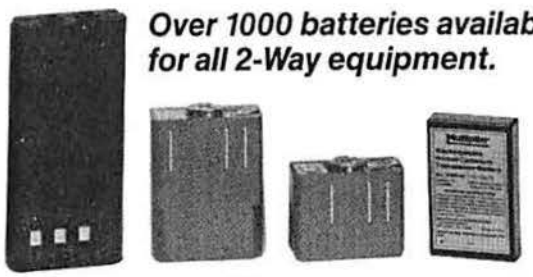

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with one another. Nevertheless, each spread spectrum user generates some degree of interference to other users, which limits the number of users who can share a given amount of spectrum.

High increases in data rates could be possible due to the wider channel bandwidths. With CDMA's extremely wide bandwidth, even more data-intensive applications could be made possible. Future CDMA implementation could make video transmission over radio communications channels possible.

CDMA's inherent low power requires many base station sites to cover even a relatively small geographic area. Coordinating a large number of sites for multi-radio group calls could bog down even the most advanced audio switches available today.

CDMA's low-power transmissions would have problems coexisting with present radio systems. Overlaying CDMA on existing spectrum would raise the noise floor for the existing users, resulting in reduced coverage and interference for those existing users.

Frequency coordination would be necessary to implement CDMA in land mobile radio to avoid interfering with existing users.

Migration

Although digital technology is a significant step in two-way communications, many users' requirements will continue to be met with analog technology for years to come.

Manufacturers must consider several migration alternatives to address the wide variety of existing analog systems. The goal is to trade out the analog system as required and maintain interoperability between analog and digital radios.

To complete a migration, users eventually will need to incorporate digital radio equipment in mobile and portable units, as well as a fixed "channel" infrastructure.

A migration must be equally flexible for single-site systems and large multiregional systems. If a migration path is laid out properly, the analog-to-digital transition would add digital benefits where needed without disrupting an existing user's radio activities.

Summary

FDMA, TDMA and CDMA can offer land mobile radio significant improvements over today's analog systems.

Each of these technologies has unique applications. FDMA provides advanced new features and improves existing features, and it improves spectrum efficiency.

TDMA provides a dramatic improvement in spectrum efficiency, along with full-duplex telephone interconnect on all mobiles and portables.

CDMA has tremendous potential for improvements in features and spectrum efficiency, but still is in early stages of research.

An important element of any digital strategy is a migration plan. A well-planned migration allows users to implement enhancements provided by digital technology.

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